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1. INTRODUCTION

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1.1 Background

1.1.1 Stratospheric Ozone Depletion. In a remarkably short period of time, the world has identified, responded to, and ameliorated a new threat to the global climate (WMO, 1995). Following a mechanism first proposed by Rowland and Molina in 1974, chemically stable chlorine-, bromine-, and iodine-containing molecules rise to the stratosphere and are quantitatively photodissociated by ultraviolet radiation. The halogen atoms then catalytically convert ozone (O_3) molecules, whose chemistry shields the earth's surface from excess ultraviolet radiation, into oxygen (O_2) molecules, which have no such filtration effect. The evidence supporting this hypothesis soon became substantial, and the international political community produced a landmark agreement in 1987, the *Montreal Protocol on Substances That Deplete the Ozone Layer*. Subsequent international amendments to this and, domestically, the U.S. Clean Air Act of 1990 have led to restrictions on both production and use of identified ozone-depleting substances (ODSs).

Halon 1301 (CF_3Br) is one of the detrimental compounds identified in this process. It is used principally as a fire suppressant, and had become the choice for many applications where effective, efficient, and clean fire control is needed. Ideally, a typical year's production of halon 1301 would be loaded into fire suppression systems, where it would reside for many years until called upon to quench the infrequent fire. In practice, most of the chemical was released sooner, in training exercises, during system testing, from discharge of the suppression system when no fire was present, or from negligent handling. In the evolving regulatory process, future uses of halon 1301 were restricted, and its production was stopped on January 1, 1994 with limited allowances made for certain developing countries.

Many of the systems being protected by halon 1301 are essential to military readiness; and in 1991, the Deputy Director, Defense Research and Engineering in the Department of Defense initiated an urgent research program to identify near-term alternatives for weapons systems use, mostly by September 1996. This research focusses on commercially available or currently emerging chemicals and technologies.

1.1.2 Aircraft Fire Suppression. One of the most important uses of halon 1301 is the suppression of in-flight fires in nearly all types of aircraft. The three military services and the Federal Aviation Administration (FAA) have pooled resources to provide solutions for a number of problems as the aviation community reduces and eventually eliminates its reliance on halon 1301. The research and engineering projects have been carried out at laboratories of the Army, Navy, Air Force and FAA, and at the National Institute of Standards and Technology (NIST). The research program focussed on two applications: engine nacelles and dry (avionics) bays, while realizing that there are other aircraft areas also in need of protection.

The requirements for engine nacelle fire protection in commercial and military aircraft are similar. The interior of the nacelle is nominally tubular in shape, often with ribs and multiple other obstructions. Two types of fires are possible: spray fires, such as from a ruptured fuel line or hydraulic fluid line, and pool fires, resulting from either liquid settling on the bottom surface of the nacelle. Either fire type can be stabilized behind an obstruction, posing an additional difficulty for the fire suppressant. Currently, halon 1301 is stored in cylinders at pressures of *ca.* 2 MPa - 4 MPa. When a thermal sensor detects an abnormal, overheated condition, the flight of the airplane is leveled and the appropriate halon 1301 bottle is discharged. The part gas, part liquid agent flows through up to several meters of tubing to the engine nacelle. Once released, it rapidly fills the nacelle volume. The certification process requires that enough agent be available to maintain a minimum concentration (*ca.* 6 % by volume) throughout the nacelle for a minimum time interval (0.5 s) to ensure that the fire will be extinguished and not re-ignite. Many systems have a duplicate bottle to be used as a back-up should the first shot be unsuccessful.

The dry bay fire is specific to military aircraft. These bays are cluttered compartments, typically 0.2 m^3 - 3 m^3 in volume, located along the wings and fuselage. An incident incendiary shell could penetrate both the bay wall and that of an adjacent fuel storage volume, leading to a deflagration and loss of the aircraft. Such fires must be quenched automatically within a few tens of milliseconds.

1.1.3 Prior Work. The first major objective of the four-agency program was to identify the optimal available alternative fluid(s) for use in suppressing fires in aircraft engine nacelles and dry (avionics) bays. This project was managed at Wright Patterson Air Force Base, with oversight provided by a Technology Transition Team of the four sponsors. In October, 1993, based on extensive laboratory research and real-scale testing at Wright-Patterson Air Force Base, the sponsors decided on a reduced list of candidates for each application:

Engine Nacelle	**Dry Bay**
C_2HF_5 (HFC-125, pentafluoroethane)	C_2HF_5 (HFC-125, pentafluoroethane)
C_3HF_7 (HFC-227ea, 1,1,1,2,3,3,3-heptafluoropropane)	C_3F_8 (FC-218, octafluoropropane)
CF_3I (trifluoroiodomethane)	CF_3I (trifluoroiodomethane)

Much of the laboratory-scale research leading to that decision was performed at NIST and has been described in *Evaluation of Alternative In-Flight Fire Suppressants for Full-Scale Testing in Simulated Aircraft Engine Nacelles and Dry Bays* (Grosshandler *et al.*, 1994). That report documents the comprehensive experimental program to screen the performance of possible suppressant chemicals as a means to identify the best candidates for subsequent full-scale aircraft fire extinguishment evaluation at Wright Laboratory, and addresses the compatibility of these agents with flight systems, people, and the environment. In particular, apparatus and measurement methods suited to aircraft applications are carefully described, and extensive performance data are provided and analyzed. The reader is referred to that report as a prerequisite and companion to the current document.

1.2 Objectives and Task Summary

The research described in this report has multiple origins, but falls into two broad categories:

Part 1: Knowledge to help differentiate among chemicals, leading to selection of the optimal currently available option(s) for in-flight fire suppression. These projects are described in Part 1. Section 2 of Part 1 (which follows this introduction) provides further data and explanation of previously identified phenomena regarding potential suppression of dry bay fires. Section 3 addresses the potential for degradation of photosensitive CF_3I following an accidental discharge. Research on the effectiveness of halon 1301 alternatives on metal fires is discussed in Section 4. Sections 5 and 6 continue to longer exposure times (from Grosshandler *et al.*, 1994) the measurements and analysis of the compatibility of the candidate agents with metals and organic materials that might be used in storage vessels. Section 7 similarly extends the prior study of the stability of the agents themselves during long-term storage.

Part 2: Knowledge to assist in the development of engineering design criteria and suppressant system certification. Section 8 develops understanding of and equations for calculating the dispersion of the agent from the storage bottle and subsequent plumbing. Section 9 provides guidance on the agent concentration requirements for flame suppression in engine nacelles. Section 10 develops a predictive capability for the formation of toxic and corrosive hydrogen fluoride (HF) during fire suppression. Section 11 reviews approaches to making the high-speed, real-time measurements of suppressant concentration needed both for research and certification, and describes our research on two of the approaches. Section 12 documents our search for and identification of a surrogate chemical for certification testing of aircraft fire suppression systems in which halon 1301 is still used.

Section 13 provides a summary of the results and puts them in the context of the fire suppression problems under consideration.

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1.4 References

Grosshandler, W.L., Gann, R.G., and Pitts, W.M., Eds., *Evaluation of Alternative In-Flight Fire Suppressants for Full-Scale Testing in Simulated Aircraft Engine Nacelles and Dry Bays*, Special Publication 861, National Institute of Standards and Technology, Gaithersburg, MD, 1994.

Molina, M.J. and Rowland, F.S., “Stratospheric Sink for Chlorofluoromethanes: Chlorine Atom-Catalyzed Destruction of Ozone,” *Nature 249*, 810 (1974).

Executive Summary, Scientific Assessment of Ozone Depletion: 1994, World Meteorological Organization, Geneva, 1995.